Using Integer Programming to Improve the Scheduling of Medical Residents

Presenter : Elizabeth Perelstein B.S. & Young-Chae Hong Ph.D.
University of Michigan

ISERC Conference 2014
Montreal, Canada

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- **Optimized Residency Scheduling Assistant (ORSA)**
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Co-Authors and Current Team Members

- Amy Cohn, Ph.D
- Jennifer Zank, M.D
- Zachary VerSchure

- Edmond O'Brien, M.D
- Gabriel Zayas-Caban, Ph.D
- William Pozehl, B.S.E.
- Daniel Hazlett, B.S.E.
- Peter Mayoros
- Nina Scheinberg
- Hannah Schapiro
- Aaron Cohen

Resident Responsibilities in the U-M Pediatric Emergency Department

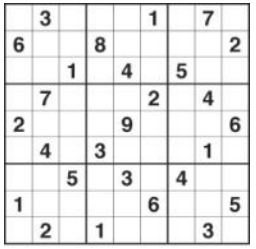
- **3-7 year medical training program**
  - **Responsibilities differ by residency year**
- **Balancing patient care and educational requirements**
  - **In hospital**
    - **Caring for patients**
    - **Teaching medical students**
    - **Learning from attending physicians**
  - **Out of hospital**
    - **Community clinics**
    - **Conferences**
    - **Other educational requirements**

Pediatric ED: Scheduling Considerations

- All shifts assigned to a resident
- Appropriate coverage
  - e.g. certain shifts require a senior resident
- ACGME rules (similar to ABET for engineering)
  - e.g. 10 hour break rule
- Several different residency programs circulate through the ED
  - Pediatrics (PED)
  - Family practice (FP)
  - Emergency medicine (EM)
- And others

Motivation

- **Scheduling Residents**
  - **Complicated requirements**
    - **25 governing rules and preferences**
      - **Educational goals**
      - **Patient care**
      - **Regularization / Safety**

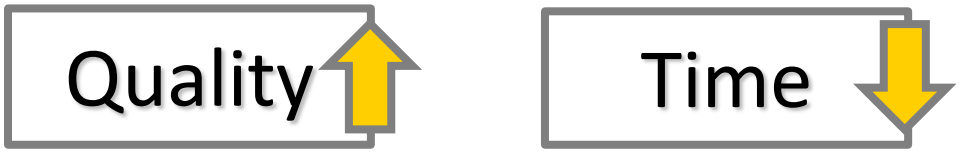


  - **Chief resident formerly built monthly schedule by hand**
    - **Time consuming process: 20 - 25 hours / month**
    - **Transfer every year: no scheduling experience in July**
    - **Guess and check: errors / tedious correction process**

Mixed Integer Programming

Motivation

- **Practical Significance**
  - Poor-quality schedule
    - Residents: decreased interest in learning
    - Patients: adverse health events
  - Expensive for the hospital
- **Goals**
  - Solves for feasible schedule quickly
  - Create a good quality schedule with no violations



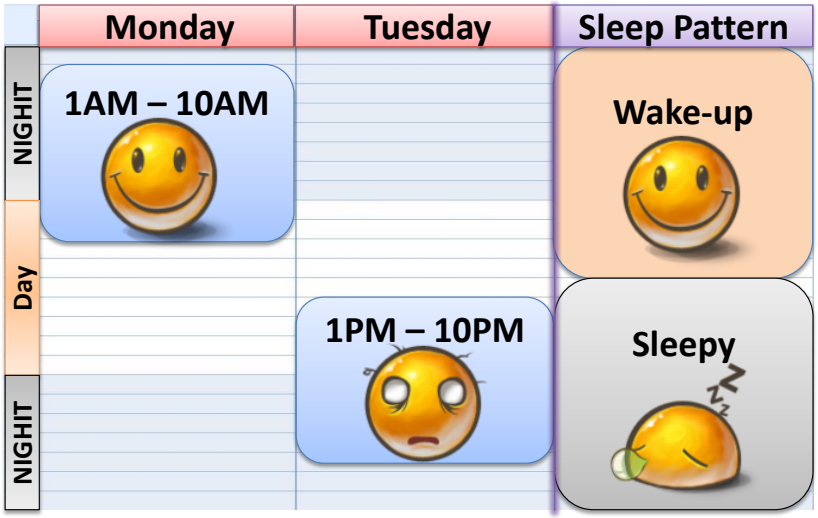
Metrics: Shift Fairness

- **Improving total / night shift equity**
  - **Equal opportunities for training**
  - **Improved morale and learning ability**

Resident Name	Smith	Jones	Chen	Joe
Night Shifts / Total Shifts	0 / 7	1 / 7	1 / 7	5 / 7
Fairness				

Metrics: Difficult Shift Transitions

- **Limit bad sleep patterns and post-clinic shifts**
  - **Improves resident quality of life**
  - **Increases patient safety**



Bad sleep pattern

Post-Clinic shift

Metrics: Difficult Shift Transitions

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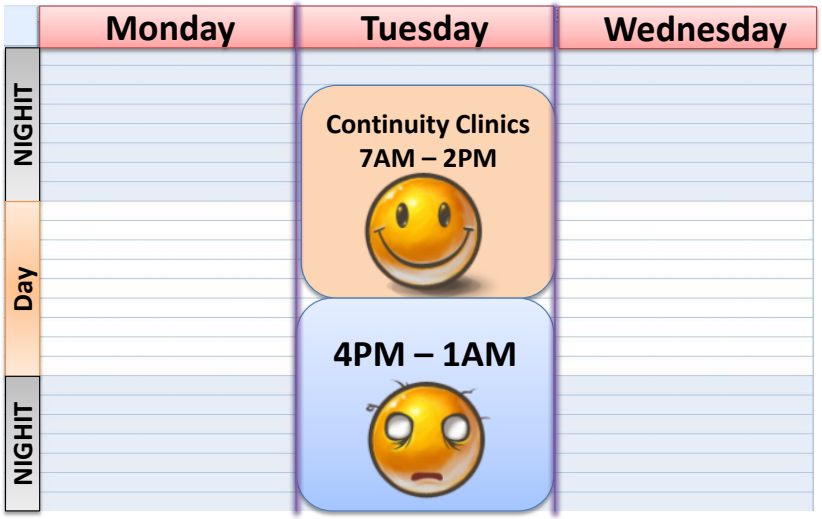
  - **Increases patient safety**

Bad sleep pattern



Post-Clinic shift

Multi-Criteria Problem

- **Multi-Criteria Schedule**
  - **Metrics for UM Pediatric Emergency Department**
    - **Total shift equity (TSE)**
    - **Night shift equity (NSE)**
    - **Minimum bad sleep patterns (BSP)**
    - **Minimum post-clinic shifts (PostCC)**
    - ⋮

Weights?
Preferences?
Trade-off?

Multi-objective Mathematical Programming

Formulation: Problem Size

- **Sets**
  - R: set of residents
    - 15-25 residents
  - D: set of days in the schedule
    - 35 days
  - S: set of shifts
    - 8 shifts
- **Decision Variables**
  - Binary: $x_{rds} \in \{0, 1\}$
    - 1 if resident r works shift s on day d
    - 0 otherwise

Residents Name				
Smith	Sanchez	Chen	Shah	…

	27th	…	1st	…	31st
7a-4p	Shah	…		…	
9a-6p	Joe	…		…	Shah
10a-7p		…		…	
12p-9p	Chen	…		…	Chen
4p-1a	Smith	…	Sanchez	…	
5p-2a		…		…	Sanchez
8p-5a	Sanchez	…	Smith	…	Smith
11p-8a		…	Chen	…	Joe

Formulation: Constraints

- **Constraints (rules/requirements)**
  - **One resident assigned to each shift in the month**
    - $\sum_{r\in\{\text{all}\}} x_{rds} = 1, \quad \forall d, \forall s$
  - **Meets shift requests**
    - $x_{rds} = 0, \quad \forall r, \forall d, s \in \{\text{day off, conferences, continuity clinic}\}$
  - **Ensure resident type appropriate for shift**
    - $\sum_{r\in\{\text{PED}\}} \sum_{s\in \text{P}} x_{rsd} \geq 1, \forall \text{d}, \text{P} = \{\{7\text{a},9\text{a}\},\{4\text{p},5\text{p}\},\{8\text{p},11\text{p}\}\}$
  - **Intern-forbidden shifts**
    - $\sum_{r\in\{\text{interns}\}} \sum_{d} x_{rsd} = 0, \forall s \in \{7\text{a}, 11\text{p}\}$
  - **And others**

Formulation: Weighted Sum Method

$$\textbf{Min } \boldsymbol{w_1}(TSE) + \boldsymbol{w_2}(NSE) + \boldsymbol{w_3}(BSPs) + \boldsymbol{w_4}(PostCC)$$
$$\textbf{s. t.} \quad \text{"rules/requirements"}$$
$$x_{rds} \in \{0,1\}$$

- **Weighted Sum Method**
  - **The Chief resident should describe preferences accurately**
- **Quantifying preferences (w_i) is difficult**
  - **Resulting schedule does not match their intentions**
  - **Various measurement unit**
    - **Equity ($\sigma(\mathbf{X})$, $\mathrm{Max}|\mathbf{X}|$, $\sum|X_i - X_j|$, …)**
  - **Some criteria are subjective and difficult to quantify**

Weighted Sum Method: Weights (w_i)

- **Matching Game**

STEP 1	Weight
TSE	2.00
NSE	1.00
PostCC	4.00
BSPs	3.00

1

STEP 2	Favorite Schedule
	2

Schedule Number	Measure of TSE	Measure of NSE	Count of PostCC	Count of BSPs
1	2	1	2	0
2	3	0	1	4
3	2	2	0	1
4	4	0	4	0

2

STEP 3	Favorite Schedule	The Best Schedule (Weight)	Do They Match?
	Schedule 2	Schedule 1	No

3

Result	Success	Fail	%
Chief 1	6	12	33.3%
Chief 2	4	15	21.1%
Chief 3	7	9	43.7%

  - **Chief residents prefer to examine schedules and choose the best solution**

Weighted Sum Method: Weights (w_i)

- **Matching Game**

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1	2	1	2	0
2	3	0	1	4
3	2	2	0	1
4	4	0	4	0

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1	2	1	2	0
2	3	0	1	4
3	2	2	0	1
4	4	0	4	0

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Optimized Residency Scheduling Assistant (ORSA): Metrics Formulation

- **Feasibility problem**
  - **Constraint on metrics**

$$\min (\textbf{weighted sum})$$
$$s.t.\ \text{"rules/requirements"}$$
$$x_{rds} \in \{0,1\}$$

$$\min \sout{(\textbf{weighted sum})}$$
$$s.t.\ \text{"rules/requirements"}$$
$$x_{rds} \in \{0,1\}$$
$$\boldsymbol{LB_1} \leq (\boldsymbol{Equity}) \leq \boldsymbol{UB_1}$$
$$\boldsymbol{LB_2} \leq (\boldsymbol{BSPs}) \leq \boldsymbol{UB_2}$$
$$\boldsymbol{LB_3} \leq (\boldsymbol{PostCC}) \leq \boldsymbol{UB_3}$$
$$\vdots$$

- **Benefits of a feasibility problem**
  - **More flexible**
  - **Faster to solve: < 2 sec.**
    - **Given: 35 days / 20 PEDs / 8 shifts**

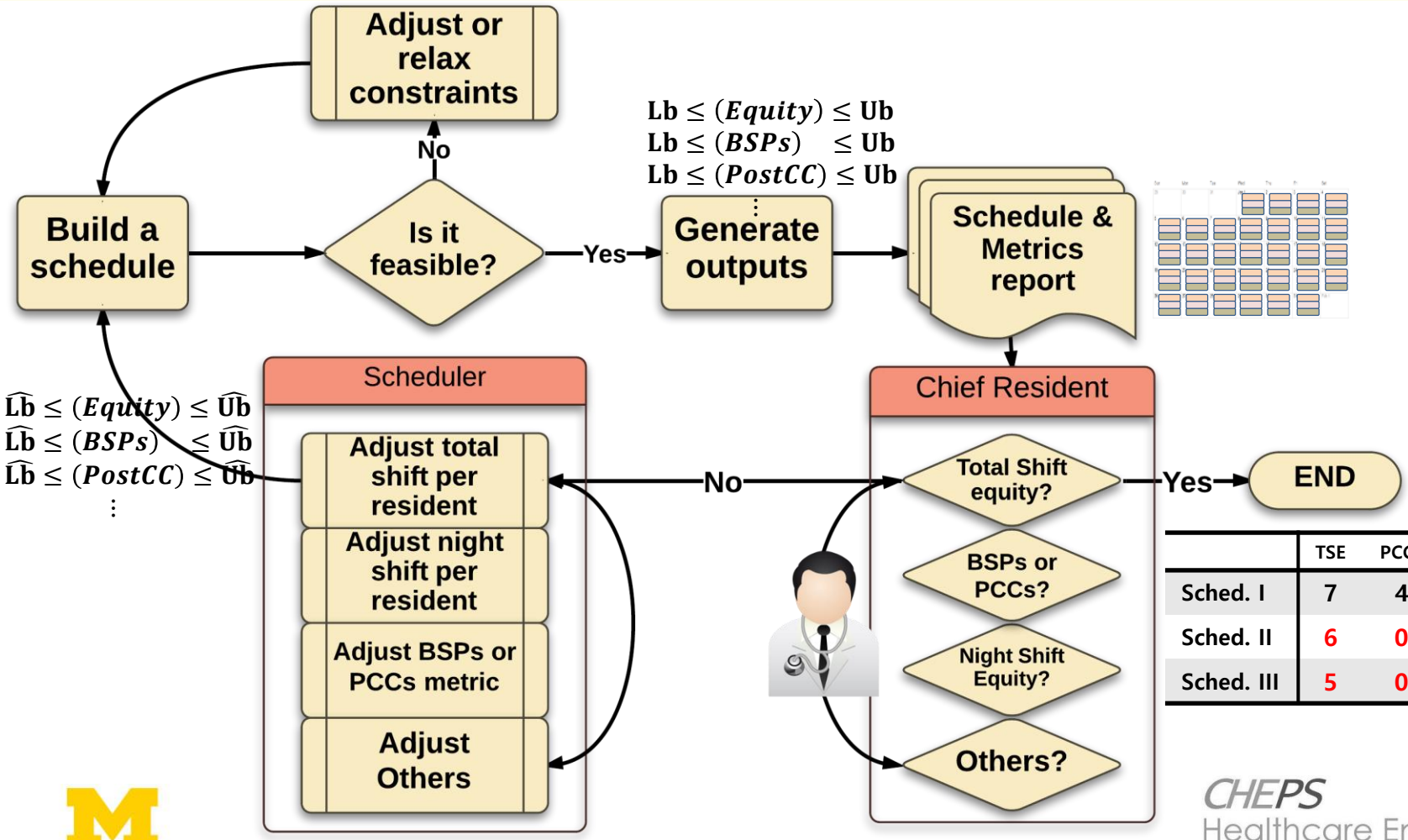
Optimized Residency Scheduling Assistant (ORSA) : Interactive Improvement

- **Example output of metrics**
  - **Value (Lower bound, Upper bound)**

Resident Name	Number of Shifts	Number of Night Shifts	Number of Post CC	Number of Bad Sleep Templates
Smith	8 (7,9)	2 (0,10)	0 (0,1)	1 (0,1)
Sanchez	8 (7,10)	1 (0,10)	0 (0,1)	1 (0,1)
Chen	8 (7,9)	5 (0,10)	1 (0,1)	1 (0,1)
Shah	14 (13,15)	3 (0,10)	1 (0,1)	1 (0,1)
⋮	⋮	⋮	⋮	⋮

- **Interactive approach engaging chief resident**
  - **Iteratively adjust bounds on metric constraints**
  - **Quickly build high quality schedule**

ORSA Methodology



	TSE	PCCs	BSPs	...
Sched. I	7	4	2	...
Sched. II	6	0	2	...
Sched. III	5	0	0	...

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Results: Completion Time

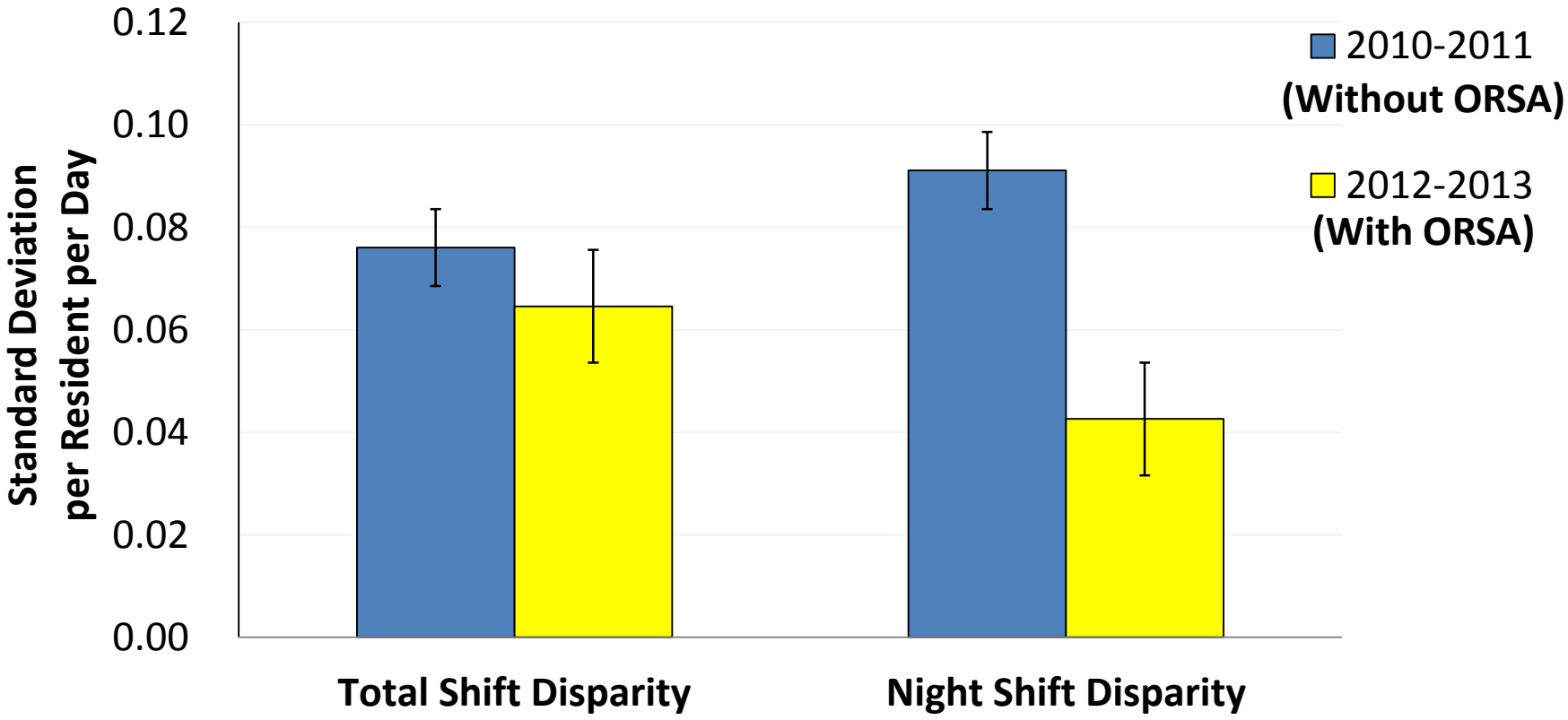
- **Schedule made by hand (2010-2011)**
  - **Per schedule: 20 - 25 hours**

	3				1		7	
6			8					2
		1		4		5		
	7				2		4	
2				9				6
	4		3				1	
		5		3		4		
1					6			5
	2		1				3	

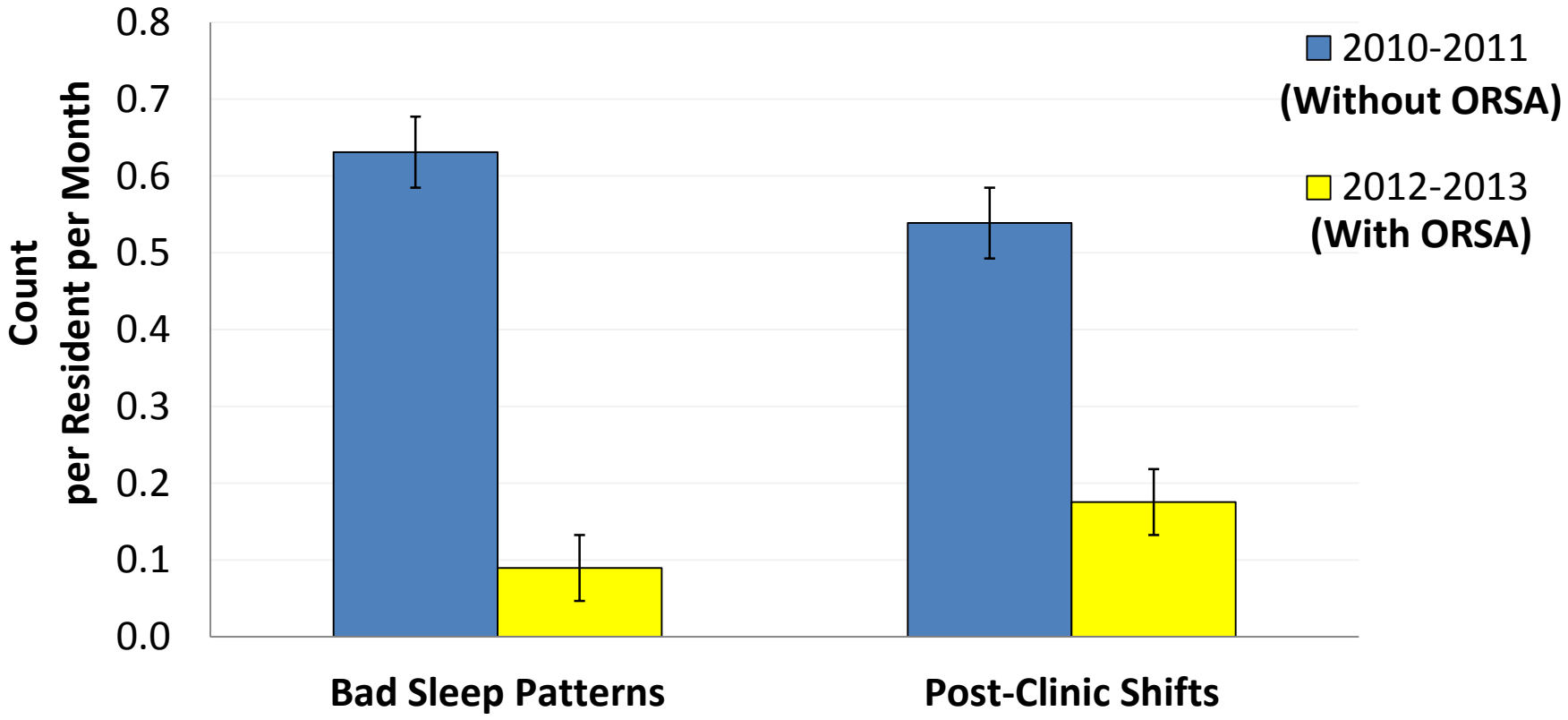
- **Schedule generated by ORSA (2012-2013)**
  - **Per iteration: < 2 sec**
  - **Per schedule: < 1 hour**

25 hours /month → **1 hour /month**

Results: Shift Fairness



Results: Difficult Shift Transitions



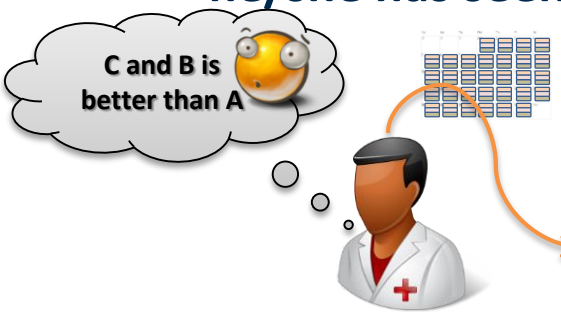
Next Steps

- **Myopic Solution**
  - **The most preferred solution is "most preferred" in relation to what he/she has seen and compare so far**

	TSE	NSE	BSPs	PCCs
Schedule A	5	4	2	1
Schedule B	4	4	1	1
Schedule C	5	3	2	0

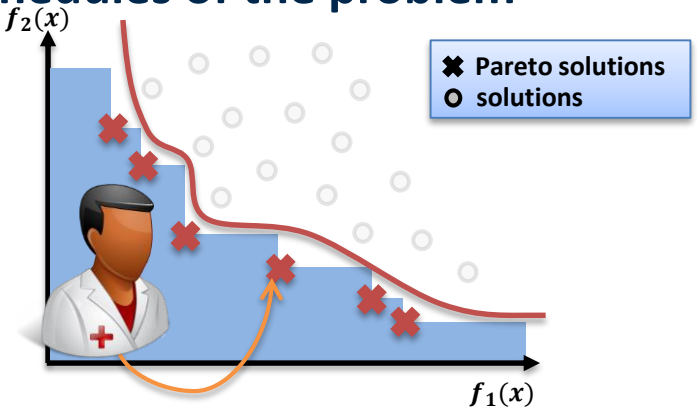
Next Steps

- **Myopic Solution**
  - The most preferred solution is "most preferred" in relation to what he/she has seen and compare so far



	TSE	NSE	BSPs	PCCs
Schedule A	5	4	2	1
Schedule B	4	4	1	1
Schedule C	5	3	2	0

  - Generate better schedules of the problem



Acknowledgements

- Thank you to CHEPS, TDC Foundation, the Bonder Foundation, and Dr. Brian Jordan, Dr. Micah Long and Dr. Jenny Zank for making this research possible.

Thank You!